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Approach of using Corn Residue as Alternative Energy Source for Power Production: A Case Study of the Northern Plain Area of Thailand

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Abstract

As Thai's energy security heavily relies on imported crude oil products, the Thai government has promoted the use of alternative energy sources as a substitute for fossil fuel through the Renewable Energy Development Plan. According to this plan, 3,630 MW of electricity should be derived from biomass or agricultural residue in 2021. Although some agricultural residue has been commercially used as fuel in biomass power plants, corn residue is still leftover and has a high energy potential in some regions, e.g. in the northern part of Thailand. This study focuses on the supply chain management in using corn residue as an alternative energy source for power production in Nakorn Sawan and Petchaboon Provinces. In 2011, almost two million tons of corn residue were generated; about 200,000 tons of which were comcob (HHV of 15-16 MJ/kg) and the rest was corn trash/skin and stems (HHV of 13-15 MJ/kg). Because of the uniform and compact shape of comcobs, they can be completely utilized as fuel in a conventional stoker-fired boiler for heat production. In contrast, corn trash/skin and stems are leftover in the field or burnt on the field without any energy recovery because they are bulky and non-uniform fuel, with high moisture content, which leads to difficulty in collection and transportation, as well as for thermal conversion. According to the results of this study, a processing unit is necessary to improve the properties of corn trash/skin and stems to be used as solid fuel. This processing unit can be established as a centralized plant or on the field where the residue is generated. Regarding the economic analysis, the overall cost of bio-pellet from corn trash/skin/stems is estimated to be 49.4-56.8 US\$ per ton, depending on the pelletizing capacity. The bio-pellets from corn residue can easily be transported to be used as feedstock for heating or power generation by direct combustion, co-firing, or gasification technology.

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1. Introduction

The increase in Thailand's population, the expansion of the Thai economy, as well as the growth of the industrial and manufacturing sectors have led to increasing demand for energy. The final energy consumption in Thailand in 2012 was 73,316 ktoe, which was an increase of 3.9% from 2011. The most important energy source used in Thailand is derived from fossil fuel, e.g. petroleum products, natural gas and coal, with an 82% share of the final energy consumption in 2012 [1]. Because Thailand has an inadequate source of crude oil and low rank coal, it has to import crude oil and good quality coal to be used for domestic consumption, resulting in a high expense of more than 1,000 million Baht (1 US\$ \approx 32 Bath) [1] in 2012, and it is expected that Thailand will continuously import crude oil and fossil energy sources in the future.. As a consequence of using fossil fuel, CO₂ is emitted during the energy conversion process. In 2012, the amount of CO₂ emission in Thailand was estimated to be 221,458 kton, where the power generation sector was the main source of CO₂ emissions (40% of total CO₂ emissions) [1].

For the above-mentioned reasons, there have been many attempts to reduce both the use of fossil fuel and CO₂ emissions by using renewable energy as a substitute for fossil fuel. This renewable energy includes solar energy, wind energy, hydro energy, as well as energy derived from biomass. Since Thailand is an agricultural-based country, there are a lot of agricultural crops, e.g. paddy rice, sugarcane, cassava, and palm oil. During the harvesting and processing of these agricultural crops, some residue is left over, e.g. rice straw and rice husk from paddy rice, bagasse and sugarcane leaves from sugarcane, cassava rhizome from cassava, as well as palm oil shell, palm oil fiber, and palm oil empty fruit bunch from palm oil fruit. These residues have a very high potential to be used as renewable energy. The Ministry of Energy of Thailand has promoted the use of biomass as alternative fuel by announcing the Renewable Energy Development Plan (REDP). The objective of the REDP is to strengthen and promote the utilization of renewable energy in order to replace imported oil. The main target of the REDP is to increase the portion of alternative energy to 25% of domestic final energy consumption by 2022 with the target of 3,630 MW heat and power production from biomass. Nowadays only 1,610 MW electrical power and 2,781 heat are produced from biomass as an energy source [2], while some types of biomass are very expensive and in very competitive demand. This study focuses on the supply chain management in using a biomass option, corn residue, as an alternative energy source, especially in the northern part of Thailand, in order to achieve the REDP's target, because it is cheap and is substantially available.

2. Research Procedure

Corn residue originated in Nakorn Sawan and Petchchaboon, two provinces in the northern part of Thailand, was used as the model in this study. The methodology to study the supply chain management includes the determination of the amount of corn residue in the focused area, the investigation of corn residue characteristics, the estimation of the energy potential, the production process of bio-fuel, and finally bio-fuel cost estimation.

2.1. Amount of Corn Residue

The amount of corn residue can be estimated according to the amount of agricultural produced, the crop to residual ratio (CRR), and the surplus availability factor (SAF). The CRR is expressed as the amount of residue generated per one unit mass of an agricultural product, and the SAF is the amount of unused residue or residue left over which is not used for any purposes. The CRR and SAF can be achieved through site surveying and conducting interviews with the farmers and the community.

2.2. Fuel Characteristics of Corn Residue

The sample of the corn residue was taken from the source. Then it was prepared by drying and grinding for analysis. The fuel characteristics analyzed are listed in Table 1.

Table 1. Analysis procedure of fuel characteristics

Proximate analysis	Method
Moisture content	D 3173
Volatile matter	D 3175
Ash	D 3174
Fixed carbon	By different
Ultimate analysis	Method
Carbon (C)	D 5373
Hydrogen (H)	D 5373
Oxygen (O)	By Different
Nitrogen (N)	D 5373
Sulfur (S)	D 3177
Heating Value	Bomb Calorimeter

2.3. Supply Chain Management of Bio-fuel from Corn Residue

The supply chain management of bio-fuel from corn residue covers the collection and transportation of residue until it is processed into bio-fuel.

2.4. Cost Estimation of Bio-pellet

Cost estimation provides the final cost of the bio-pellet produced from the corn residue. This includes the cost of the residue, the cost of harvesting and collection, the cost of transportation, and the cost of pellet production. All sub-costs were obtained by interviewing and site surveying.

3. Results and Discussion

3.1. Amount of Corn Residue

Table 2. CRR and amount of corn residue in Petchaboon and Nakorn Sawan in 2011

	Product (ton/year)	Residues	CRR	Available residues (ton/year)
Petchaboon	675,140	Trash/skin/stems	1.95	1,315,971
		Corn cob	0.19	128,277
Nakorn Sawan	299,737	Trash/skin/stems	1.76	529,475
		Corn cob	0.19	56,950

In 2011, Thailand had an area of corn cultivation of more than 6 million Rai (1 Acre = 2.5 Rai), which could produce 4.6 million tons of corn. The main area of corn cultivation in Thailand is located in the northern part of Thailand. In 2011, approximately two million tons of corn residue were generated, about

200,000 tons of which was corncob and the rest was corn trash/skin and stems. Because of the uniform and compact shape of corncobs, they can be completely utilized as fuel in a conventional stoker-fired boiler for heat production. In contrast, corn trash/skin and stems are leftover in the field or burnt on field without any energy recovery because they are bulky and non-uniform fuel, with high moisture content, which leads to difficulty in collection and transportation, as well as thermal conversion. Hence, the corn residue to be considered in this study is trash/skin/stems only. Table 2 shows the CRR as well as the amount of corn residue in Petchaboon and Nakorn Sawan in 2011.

3.2. Fuel Characteristics of Corn Residue

The characteristic used to indicate the energy potential of biomass is its heating value. In addition to heating value, proximate and ultimate analysis is also an important indicator for converting biomass to energy. Table 3 shows the fuel characteristics of corn residue obtained from Petchaboon and Nakorn Sawan. It can be concluded that the corncobs and trash/skin/stems from Petchaboon and Nakorn Sawan have almost the same characteristics. The higher heating value ranges from 15-16 MJ/kg for corncobs to 13-15 MJ/kg for trash/skin/stems. After harvesting for 2 weeks, the moisture content of the corncobs was less than 10%, where the moisture content of the trash/skin/stems varied from 6% to 12%.

Table 3. Fuel characteristics of corn residue in Petchaboon and Nakorn Sawan

	Petchaboon		Nakorn Sawan	
	Trash/skin/stems	Corncob	Trash/skin/stems	Corncob
Proximate analysis				
Moisture content ¹ (%)	6.12	9.97	11.90	9.94
Volatile matter ² (%)	73.35	83.13	78.85	84.71
Ash ² (%)	7.20	1.98	5.60	2.33
Fixed carbon ² (%)	19.45	14.89	15.55	12.96
Ultimate analysis ² (%)				
Carbon (C)	44.53	44.83	44.65	47.00
Hydrogen (H)	5.88	6.01	6.50	6.55
Oxygen (O)	42.16	47.07	46.18	44.75
Nitrogen (N)	0.17	0.05	2.68	1.66
Sulfur (S)	0.047	0.056	0.027	0.055
HHV (kJ/kg)	14,975	15,073	13,157	16,093

¹ As received basis (after 2 weeks of harvesting)

² Dry basis

3.3. Supply Chain Management of Bio-fuel from Corn Residue

The supply chain management begins with the harvesting or collection of the biomass and then proceeds to transportation and finally the processing of corn residue into bio-fuel. For the reason explained previously, this section will consider only trash/skin/stems as alternative energy sources.

Collection: The harvesting and collecting of corn trash/skin/stem residue can be done by machine. However, the machinery is very expensive and the geography of the northern part of Thailand is mountainous, which limits the collection ability by large machines, and therefore the manual collection of

corn trash/skin/stems is the most suitable method. With manual collection, trash/skin/stems should be left on the field for one week until the moisture content can be reduced to 15%. One labor can collect trash/skin/stems in the area of 0.5 Rai, which corresponds to 501.28 kg of trash/skin/stems (15% moisture content).

Transportation: After collection from the field, the corn trash/skin/stems should be piled up to facilitate the handling. Theoretically, tractors are not suitable for biomass transportation for long distances; the most suitable way to transport corn residue is by truck. Because corn residue is very bulky, only 4 tons of corn residue can be transported by truck.

Processing of corn residue into bio-pellet: Prior to using corn residue as fuel, processing, e.g. drying, grinding, and pelletizing of the corn trash/skin and stems, is necessary to improve their properties so that they can be used as solid fuel. The corn residue should be dried until the moisture content is less than 15%. The processing unit consists of a shredder and pelleting machine and it can be operated in two ways. The first is installing the processing unit on-field (decentralized), and the second way is to set up a centralized processing unit. To operate the decentralized processing unit, the transportation of corn trash/skin and stems is not required. Each cultivation area will have one processing unit for operation in the field, and the capacity of the processing unit should not exceed 100 kg/h. For the centralized processing unit, corn trash/skin and stems must be delivered to the processing plant and the distance of transportation should not be more than 20 km. According to this study, it is feasible to establish a centralized process unit in each district in Nakorn Sawan and Petchaboon.

Transportation of bio-pellet: The bio-pellets from the corn residue can easily be transported a long distance to be used as feedstock for heating or power generation by direct combustion, co-firing, or gasification technology. The bio-pellets can be transported by truck. Due to the high density of the bio-pellets, one full truck can transport 15 tons of pellets. Cost Estimation of Bio-pellets

Feedstock cost: Because corn trash/skin/stems are left over in the field as waste and are not used for any other purpose, the cost of feedstock itself is null.

Collection cost: The collection cost was performed using manual collection. In this study, the collection cost of the corn trash/skin/stems was 19.95 US\$ per ton of dry trash/skin/stems.

Transportation cost: The transportation cost can be separated into the transportation of corn trash/skin/stems to the processing unit for the centralized unit and the transportation of bio-pellets for the end user in industry. The cost of transportation was calculated based on the normal price of hiring a truck in Thailand. The transportation cost of the corn trash/skin/stems to the processing unit for the centralized unit was estimated to be 16.67 US\$ per ton for the short distance of 20 km, while the transportation of the bio-pellets to the industrial plants was 6.67 US\$ per ton for the distance of 100 km.

Processing cost: Two model process units, as described above, were used for calculation including investment cost, electricity cost, maintenance cost, and labor cost. For the large processing unit can produce cheaper bio-pellets than the small processing unit. The processing cost ranges from 17.7 US\$ per ton for the 2 t/h processing unit to 30.2 US\$ per ton for the 100 kg/h processing unit. The production cost of the bio-pellet from corn trash/skin/stems cover all of the costs mentioned above.

The total production cost of the bio-pellets from corn trash/skin/stems depends on the scenario. For scenario 1 where the 100 kg/h processing unit is located on-field (decentralized), the production cost was 56.85 US. For scenario 2 and where the 1 t/h and 2 t/h processing unit was established as centralized, the production cost was 50.75 US\$ and 49.35 US\$.

4. Conclusion and Recommendations

This study focused only on the supply chain management of bio-pellet production from corn residue. The processing unit, e.g. drying, grinding, and pelletizing of corn trash/skin and stems, is necessary to

improve the properties of corn trash/skin and stems to be used as solid fuel. This processing unit can be established as centralized or in the field where the residue is are generated. Regarding the economic analysis, including the raw material cost, collection cost, transportation cost, and processing cost, the overall cost of the bio-pellet from corn trash/skin and stems was estimated to be 49.4-56.8 US\$ per ton depending on the pelletizing capacity. This bio-pellet has high heating value and can further be used as alternative or supplementary fuel in industrial plants or biomass power plants for heat and power production via combustion or gasification technology. The supply chain management should be extended to cover heat and power production in the future. In addition to studying supply chain management, this study also focused on the policy to promote energy production from biomass. According to this study, public participation at all levels is necessary, beginning with clear government policies to making agriculturists and others realize the negative impact of burning agricultural residue on-field. Additionally, Thai policies should focus on the importance of using agricultural residue as a substitute for fossil fuel for energy production in order to reduce imported fossil fuel and the global warming problem. According to this study, the government policies should be divided into 3 parts: first is to raise public awareness and public participation; second is to promote and support the use of agricultural residue; and third is to develop and improve the process in Thailand.

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